Establishment of *Phyllonorycter mespilella* (Hübner) (Lepidoptera:Gracillariidae) and its parasitoid, *Pnigalio flavipes* (Hymenoptera:Eulophidae), in fruit orchards in the Okanagan and Similkameen Valleys of British Columbia

J. E. COSSENTINE AND L. B. JENSEN

AGRICULTURE CANADA RESEARCH STATION SUMMERLAND, BRITISH COLUMBIA V0H 1Z0

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ABSTRACT

In 1988, a leafminer, *Phyllonorycter mespilella* (Hübner) (Lepidoptera:Gracillariidae) was found for the first time in commercial fruit orchards in the Okanagan and Similkameen valleys of British Columbia after apparently moving across the international border from Washington State. Leafminer infestations and parasitoid-induced-leafminer-mortalities were assessed in widespread surveys in the two orcharding areas from 1988 to 1990. *Pnigalio flavipes* (Hymenoptera:Eulophidae) was the primary parasitoid of the leafminer pest. Three additional parasitoid species associated with the leafminer host in 1990 were: a *Sympiesis* species, an *Eulophus* species and a *Cirrospilus* species (Hymenoptera:Eulophidae). Parasitism reduced intraseasonal leafminer population increase as parasitoid-induced-mortality in the first leafminer generation of 1989 and 1990 was negatively correlated with leafminer density in both the second and third generations of the same year.

Key words: Insecta, *Phyllonorycter mespilella*, leafminer, parasitism.

INTRODUCTION

The leafminer pest of several economically important tree fruit-crops in western North America, previously misidentified as *Phyllonorycter elmaella* Doğanlar & Mutuura (Lepidoptera:Gracillariidae), has been identified as *Phyllonorycter mespilella* (Hübner) by J.-F. Landry (Centre for Land and Biological Resources Research, Ottawa) and D. Wagner (University of Connecticut, Storrs). Although low infestations of this leafminer cause minimal apple damage, severe infestations in apple orchards can result in premature ripening, leaf and fruit drop, reductions in apple firmness, size, color and storage life, and reduced foliar absorption of growth regulators (Hoyt 1983).

This leafminer was a minor orchard pest throughout the Pacific Northwest of the United States until the species developed resistance to commonly used organophosphate and chlorinated-hydrocarbon orchard chemical sprays (Hoyt 1983). The only chemical currently registered for successful control of the resistant pest species on apple in the United States is a carbamate; a chemical that is toxic to predaceous mites and therefore disrupts established nonchemical integrated mite management programs.

Parasitism has been reported to cause major mortality in *Phyllonorycter* spp. (Barrett 1988, Doğanlar and Beirne 1980, Pottinger and LeRoux 1971). *Pnigalio flavipes* (Ashmead) (Hymenoptera:Eulophidae), the key parasitoid of the leafminer pest in Washington State (Barrett 1988), has been shown to have the potential to reduce the leafminers' intraseasonal population increase and to keep its host's density below treatment levels (Barrett and Brunner 1990).

Phyllonorycter elmaella was described in British Columbia on apples in the Vancouver area (Doğanlar and Mutuura 1980), however the species has not been recorded in areas of commercial orcharding in the Okanagan and Similkameen valleys. This study reports surveys conducted from 1988 to 1990 to verify the establishment and spread of *P. mespilella* and its associated parasitoids, into apple orchards in the interior of British Columbia.

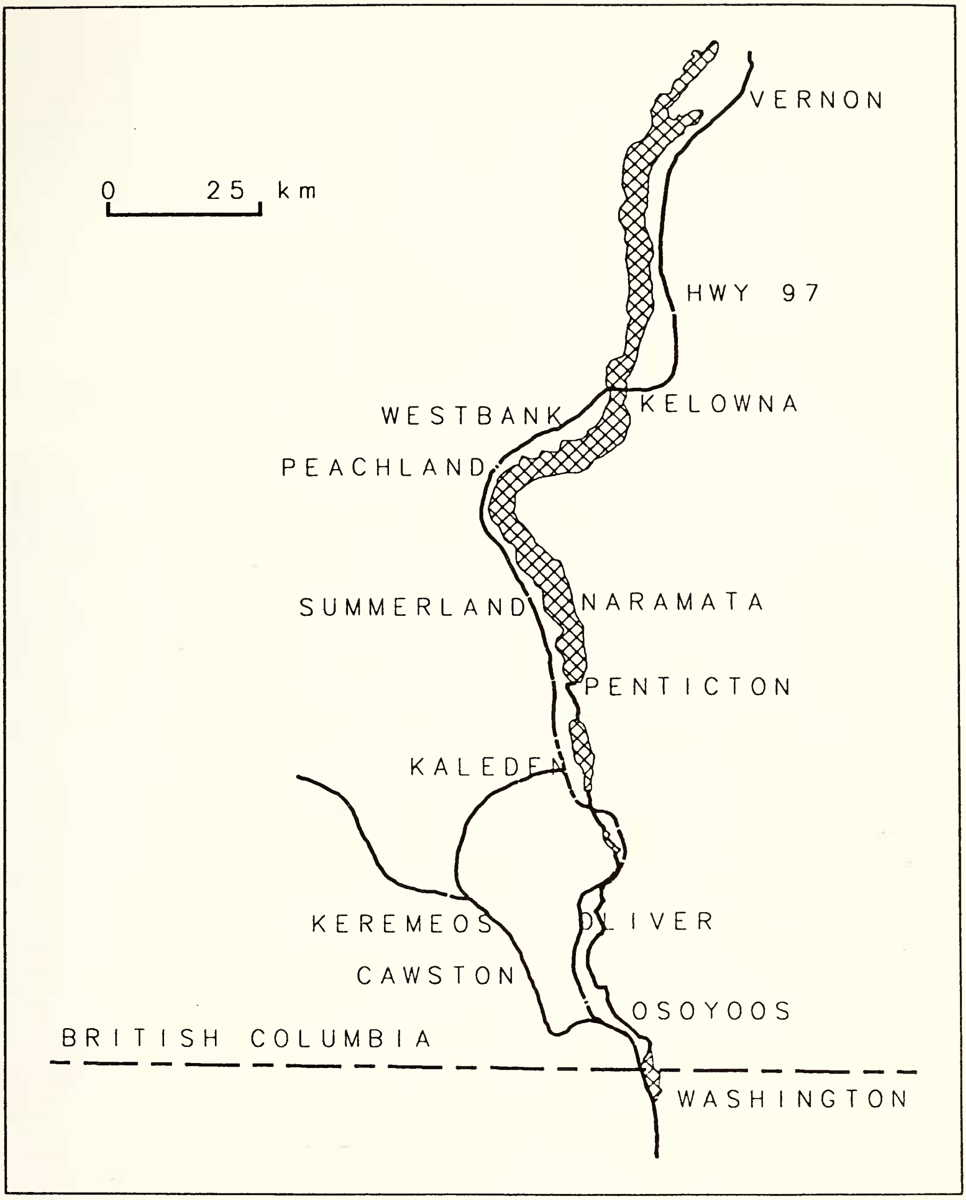

Figure 1. Area of the Okanagan and Similkameen valleys included in the leafminer survey.

MATERIALS AND METHODS

In the first *P. mespilella* generation of 1988, three orchards in Osoyoos, where the original infestation was found, and in the second generation, 13 orchards from Osoyoos to Kaleden were surveyed. In the third generation of 1988, 33 orchards from Osoyoos to Vernon (Okanagan Valley) as well as eight orchards in Keremeos and Cawston (Similkameen Valley) were surveyed in a similar fashion (Fig. 1). In 1989 and 1990 from 28 to 42 of the same orchards in the two valleys were surveyed in each of the three leafminer generations (Table 1). Surveys were conducted during the tissue-feeding stage of each leafminer generation. All orchard sites, save one in each of the Okanagan and Similkameen Valleys, were exposed to azinphosmethyl treatments for summer codling moth control.

Table 1

Mean leafminers found per minute of searching time in orchards in the Similkameen and Okanagan Valleys of British Columbia, 1988-1990.

Orchard Area (km north)[a]	Gen[b]	Mean mines found per minute[c] ± sd 1988 (n)[d]	1989 (n)	1990 (n)
Keremeos	1	—[e]	1.43 ± 1.82 (8)	1.72 ± 1.58 (8)
(20 km)	2	—	1.33 ± 1.32 (8)	5.19 ± 4.35 (8)
	3	3.49 ± 4.79 (8)	2.55 ± 2.48 (8)	61.91 ± 24.91 (8)
Osoyoos	1	0.10 ± 0.00 (3)	0.99 ± 1.07 (6)	1.29 ± 0.52 (5)
(0 km)	2	1.21 ± 0.73 (6)	0.43 ± 0.42 (6)	2.33 ± 1.52 (5)
	3	6.59 ± 4.10 (6)	5.84 ± 6.40 (6)	30.25 ± 23.77 (5)
Oliver	1	—	0.18 ± 0.11 (6)	0.75 ± 0.38 (5)
(20 km)	2	0.14 ± 0.16 (5)	0.07 ± 0.08 (6)	1.60 ± 0.83 (5)
	3	0.45 ± 0.37 (5)	1.52 ± 0.94 (6)	23.25 ± 16.22 (5)
Vaseux Lake	1	—	1.22 ± 1.85 (3)	0.07 ± 0.08 (3)
to Kaleden	2	0.28 ± 0.25 (2)	0.15 ± na[f] (1)	0.43 ± 0.33 (3)
(31-43 km)	3	0.30 ± 0.30 (3)	1.50 ± 0.85 (3)	10.08 ± 11.04 (3)
Penticton	1	—	0.08 ± 0.15 (4)	0.49 ± 0.78 (4)
(49 km)	2	—	0.14 ± 0.21 (4)	9.24 ± 5.95 (4)
	3	0.03 ± 0.05 (4)	1.05 ± 1.38 (4)	43.44 ± 47.84 (4)
Naramata	1	—	0.42 ± 0.72 (3)	5.62 ± 6.59 (3)
(64 km)	2	—	0.50 ± 0.74 (3)	27.62 ± 26.84 (3)
	3	0.02 ± 0.05 (3)	1.08 ± 0.88 (3)	129.50 ± 69.68 (3)
Summerland	1	—	—	0.13 ± 0.14 (3)
(67 km)	2	—	—	1.07 ± 1.11 (3)
	3	0.00 ± 0.00 (3)	0.08 ± 0.08 (3)	12.83 ± 11.58 (3)
Peachland to	1	—	—	0.00 ± 0.00 (2)
Westbank	2	—	—	0.40 ± 0.57 (2)
(87-92 km)	3	0.00 ± 0.00 (2)	0.00 ± 0.00 (2)	4.73 ± 2.86 (2)
Kelowna	1	—	—	0.00 ± 0.00 (3)
(92 km)	2	—	—	0.00 ± 0.00 (3)
	3	0.00 ± 0.00 (3)	0.00 ± 0.00 (3)	1.10 ± 0.43 (3)
Vernon	1	—	—	0.01 ± 0.03 (4)
(137 km)	2	—	—	0.21 ± 0.39 (4)
	3	0.00 ± 0.00 (4)	0.00 ± 0.00 (4)	11.26 ± 20.36 (4)

[a] Kilometers north of Canada/United States border
[b] Leafminer generation
[c] Derived from 10 minute visual search
[d] Number of orchards included in mean
[e] Unrecorded
[f] Only one orchard surveyed therefore no standard deviation of mean

An orchard survey involved a ten-minute visual search by two individuals experienced in mine recognition. In 1990, the survey time was reduced to two-minutes in orchards where more than 50 mines were counted per minute. Leaves in the orchards were examined continuously during the time period, both on the upper and lower surfaces because sapfeeders (the early feeding stage of the leafminer) are visible only on the underside of the leaf. All leafminer-infested leaves observed were collected and taken to the laboratory. Each mine was examined under a stereomicroscope and the stages of leafminers and parasitoids present were recorded. Empty mines, whose previous occupants could not be determined, were included in total mine counts in the first generation only.

Leafminers were recorded as parasitized when an ectoparasitoid egg, larva, pupa, or adult was found in the mine. A round parasitoid exit hole on the surface of the mine was recorded as parasitized in the first generation count only. Dead leafminers were considered to have been host fed or stung.

Table 2

Mean percent parasitism of leafminers in the Similkameen and Okanagan Valleys, 1988-1990.

	Gen[b]	**Mean percent parasitism ± sd**		
Orchard Area (km north)[a]		**1988 (n)**[c]	**1989 (n)**	**1990 (n)**
Keremeos	1	—[d]	41.36 ± 15.46 (8)	26.19 ± 16.66 (8)
(20 km)	2	—	31.25 ± 24.15 (8)	25.56 ± 13.59 (8)
	3	17.10 ± 11.53 (8)	16.43 ± 10.78 (8)	30.11 ± 13.58 (8)
Osoyoos	1	0.00 ± 0.00 (2)	64.39 ± 29.02 (6)	40.52 ± 16.44 (5)
(0 km)	2	38.36 ± 28.27 (6)	11.10 ± 12.31 (6)	22.91 ± 15.39 (5)
	3	61.23 ± 20.99 (6)	23.09 ± 10.30 (6)	21.71 ± 2.69 (5)
Oliver	1	—	37.22 ± 37.14 (6)	33.96 ± 16.59 (5)
(20 km)	2	4.17 ± 7.21 (3)	5.00 ± 10.00 (6)	17.50 ± 6.53 (5)
	3	37.14 ± 18.42 (5)	33.94 ± 20.38 (6)	25.67 ± 13.38 (5)
Vaseux Lake	1	—	32.09 ± 27.85 (3)	16.67 ± 23.57 (2)
to Kaleden	2	na[e]	0.00 ± na (1)	50.00 ± 16.67 (3)
(31-43 km)	3	na	25.84 ± 17.36 (3)	35.26 ± 13.09 (3)
Penticton	1	—	16.67 ± na (1)	1.52 ± 3.03 (4)
(49 km)	2	—	5.56 ± 7.86 (2)	37.08 ± 10.38 (4)
	3	0.00 ± na (1)	34.28 ± 16.79 (2)	14.30 ± 7.15 (4)
Naramata	1	—	36.00 ± na (1)	6.32 ± 7.17 (3)
(64 km)	2	—	5.56 ± 7.86 (2)	18.12 ± 12.36 (3)
	3	0.00 ± na (1)	17.33 ± 20.17 (3)	16.54 ± 2.45 (3)
Summerland	1	—	d	22.22 ± 38.49 (3)
(67 km)	2	—	d	39.39 ± 17.91 (3)
	3	na	0.01 ± 0.00 (2)	31.02 ± 16.07 (3)
Peachland to	1	—	d	na
Westbank	2	—	d	37.50 ± na (1)
(87-92 km)	3	na	na	9.26 ± 7.86 (2)
Kelowna	1	—	d 0.00 ± na (1)	
(92 km)	2	—	d	6.25 ± na (1)
	3	na	na	3.44 ± 6.89 (4)
Vernon	1	—	d 0.00 ± na (1)	
(137 km)	2	—	d	0.00 ± na (1)
	3	na	na	4.46 ± 6.31 (2)

[a] Kilometers north of Canada/United States border

[b] Leafminer generation

[c] Total orchards included in mean[d]Unrecorded

[e] Only one orchard surveyed or no leafminer found, therefore percent parasitism irrelevant

To compare the estimate of leafminer density using timed mine surveys with that obtained by randomly collecting 100 leaves (Barrett and Brunner 1990, Hoyt 1983), both techniques were carried out at 34 orchard sites in the two valleys in the third generation of 1989 as well as the first generation of 1990. The percentage of mines per 100 leaves was compared with the number of mines found per 10 min per person using a Spearman correlation (SAS 1985).

Pheromone traps baited with spotted tentiform leafminer, *Phyllonorycter blancardella* (Fabricius), pheromone were hung in sample orchards where the leafminer had not previously been recorded. Samples of adult parasitoids were fixed in alcohol and sent to the Biosystematics laboratory in Ottawa for identification.

Table 3

Mean percent dead leafminers in orchards of the Similkameen and Okanagan Valleys, 1988-1990.

	Gen[b]	**Mean percent dead leafminers ± sd**		
Orchard Area (km north)[a]		**1988 (n)[c]**	**1989 (n)**	**1990 (n)**
Keremeos (20 km)	1	—[d]	8.92 ± 11.40 (8)	11.93 ± 9.15 (8)
	2	—	10.82 ± 10.08 (8)	12.60 ± 7.08 (8)
	3	—	51.21 ± 13.25 (8)	38.82 ± 7.67 (8)
Osoyoos (0 km)	1	0.00 ± 0.00 (8)	10.68 ± 13.90 (6)	17.59 ± 10.83 (5)
	2	9.04 ± 4.69 (6)	35.56 ± 24.75 (6)	10.14 ± 2.82 (5)
	3	—	50.94 ± 14.05 (6)	47.47 ± 9.11 (5)
Oliver (20 km)	1	—	40.56 ± 41.11 (6)	13.52 ± 7.83 (5)
	2	0.00 ± 0.00 (3)	55.00 ± 52.60 (4)	18.47 ± 10.10 (5)
	3	—	44.11 ± 17.69 (6)	43.75 ± 1.44 (5)
Vaseux Lake to Kaleden (31-43 km)	1	—	45.15 ± 48.06 (3)	33.33 ± 47.14 (2)
	2	0.00 ± na[e] (1)	66.67 ± na[e] (1)	8.15 ± 7.14 (3)
	3	—	27.88 ± 8.20 (3)	31.32 ± 18.57 (3)
Penticton (49 km)	1	—	0.00 ± 0.00 (1)	3.03 ± 6.06 (4)
	2	—	0.00 ± 0.00 (2)	28.15 ± 4.01 (4)
	3	—	25.13 ± 8.35 (2)	37.37 ± 17.35 (4)
Naramata (64 km)	1	—	16.00 ± na (1)	7.91 ± 6.03 (3)
	2	—	3.70 ± 5.24 (2)	12.58 ± 4.15 (3)
	3	—	13.45 ± 12.17 (3)	36.66 ± 5.38 (3)
Summerland (67 km)	1	—	—	0.00 ± 0.00 (3)
	2	—	—	9.73 ± 8.43 (3)
	3	na	58.33 ± 11.79 (2)	21.47 ± 10.02 (3)
Peachland to Westbank (87-92 km)	1	—	—	na
	2	—	—	0.00 ± na (1)
	3	na	na	14.82 ± 5.24 (2)
Kelowna (92 km)	1	—	—	0.00 ± na (1)
	2	—	—	0.00 ± na (1)
	3	na	na	4.49 ± 8.98 (4)
Vernon (137 km)	1	—	—	0.00 ± na (1)
	2	—	—	0.00 ± na (1)
	3	na	na	3.57 ± 5.05 (2)

[a] Kilometers north of Canada/United States border
[b] Leafminer generation
[c] Total orchards included in mean
[d] Unrecorded
[e] Only one orchard surveyed or no leafminer found therefore percent parasitism irrelevant

RESULTS AND DISCUSSION

A visual inspection of a defined number of randomly sampled leaves per orchard site (Barrett and Brunner 1990, Hoyt 1983) was not used as a survey technique because very low infestations could easily be left unrecorded using this method. The timed mine count used in the survey was significantly correlated with the mine count in randomly collected leaves (R =0.82, P=0.0001, n = 67). Therefore, we conclude that the timed survey was realistic both in terms of finding extremely low infestations as well as estimating mine density.

In 1988, low infestations of the *P. mespilella* were widespread in surveyed orchards in Keremeos and Cawston in the southern Similkameen Valleys, and from Osoyoos to Naramata in the Okanagan Valley (approximately 20 to 23 km and 0 to 64 km N of the international border respectively) (Table 1). The leafminer was found in two of the three Osoyoos orchards surveyed in the first generation of 1988, suggesting that the species may have been present in the Okanagan valley by the Fall of 1987. Leafminer infestations decreased in density in orchards from the S to N of the Okanagan Valley (Table 1), suggesting that the species crossed the international border in the interior of the province.

Pnigalio flavipes, the primary tentiform leafminer parasitoid species in Washington State (Barrett 1988) and the second most dominant *Phyllonorycter* parasitoid in Utah (Barrett and Jorgensen 1986) was found in 87% (n=101 mines) of the leafminer hosts in the southernmost orchard surveyed in the Okanagan Valley in 1988. *Pnigalio flavipes* was not listed as one of the 12 parasitoid species reared from the *P. elmaella* in the Vancouver area of British Columbia from 1976 to 1977 (Doğanlar and Beirne 1980) indicating that this species also crossed the international border from Washington State orchards. No parasitism was found N of Oliver in 1988 (Table 2), however leafminer infestations were so low from Oliver to Summerland that it is possible that the parasitoid was present but not intercepted.

In 1989, leafminers were not found in pheromone or visual orchard surveys north of Summerland and Naramata. The density of leafminer infestations, as determined by mines found per minute, remained low throughout the south Okanagan and Similkameen Valleys (Table 1) even though parasitism in these regions was as high as 64.39 ± 29.02 percent (Table 2). Multiparasitism rather than superparasitism may have been what was evident in orchards with high rates of parasitism.

In 1990, low numbers of the *P. mespilella* were found as far N as Vernon (approximately 137 km north of the international border) (Table 1). The highest leafminer counts were found in the Naramata survey area, however even these numbers had not reached the treatment threshold of one, two or five mines per leaf in the first, second or third leafminer generations respectively, as recommended for control of *P. mespilella* for Washington State growers (Hoyt 1983).

Three additional parasitoid species were identified in survey orchards from Osoyoos to Summerland in 1990. The second most abundant parasitoid was identified as a *Sympiesis* sp. (Hymenoptera: Eulophidae) and the remaining two parasitoids as *Eulophus* sp. and *Cirrospilus* sp. (Hymenoptera:Eulophidae). Percent parasitism per species was not determined as not all of the parasitoids survived after the survey mines had been opened and inspected.

The percentage of dead leafminers in the 1989 and 1990 surveys was generally high in infested areas (Table 3) (3.57 to 51.21% in the third generation). Adult *Pnigalio* species can kill host larvae by stinging the host while ovipositing, as well as by feeding on the larvae. Van Driesche and Taub (1983) also recorded death induced by *Sympiesis marylandensis* stinging host larvae without oviposition. Percent parasitism combined with percent dead leafminers (parasitoid-induced-mortality) is probably most indicative of the total impact that the *Pnigalio* parasitoid is having on the leafminer host (Barrett 1988).

Phyllonorycter mespilella density in both the second and third generations in 1989 and 1990 was significantly (P=0.0001) and negatively correlated with parasitoid-induced-mortality in the first generation of the same years (r=-0.68 and r=-0.63 respectively, n= 39). Parasitoid-induced-mortality in the second generation did not correlate significantly (P >.05) with host density in the first, second or third generation. Parasitoid-induced-mortality in the third generation was significantly negatively correlated with host density in the second (r = -0.40, P = 0.01, n = 39) and third generations (r = -0.34, P = 0.03, n = 39). *Pnigalio flavipes* in Washington State was found to respond to its tentiform leafminer host in a density dependent manner (Barrett 1988) and to reduce the leafminer's intraseasonal population increase.

The *P. flavipes* and its host survived the azinphosmethyl codling moth treatments applied in all but two of the orchards in this survey. Resistance of the parasitoid to commonly used orchard pesticides and the parasitoid's ability to reduce leafminer density in the second and third generation supports parasitism as a realistic integrated strategem against leafminers that is preferable to a carbamate-insecticide alternative.

High standard deviation of mean leafminer counts, percent parasitism and mortality throughout the survey is indicative of the high variation between orchards even within a given region. This variation should subside with time as the new pest and its parasitoid complex become established throughout the orcharding area.

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